

Summary

Cardiovascular pathologies are the leading cause of death worldwide. Therefore, crucial effort has been made to provide a solid understanding of hemodynamics in presence of cardiovascular pathologies and implantable devices. Various methods have been employed to study blood fluid dynamics, including *in vitro* experiments. Experimental measurements play a crucial role in studying cardiovascular flows, providing foundational insights into the mechanics of blood flow and aiding the development of computational models and clinical practices. In fact, they allow the acquisition of data that *in vivo* cannot be obtained, or that can be obtained only invasively, and these data can be employed to fine-tune boundary conditions and material properties in computational fluid dynamic (CFD) simulations. Moreover, experimental results can be used to validate CFD models and in the development of diagnostic techniques based on images (e.g. Doppler ultrasound improvements or MRI).

Besides, *in vitro* studies play a crucial role in the development, optimization, and validation of cardiovascular devices, such as stents, grafts, or heart valves. Regulatory bodies, such as the Food and Drug Administration (FDA) or the European Medicines Agency (EMA), require experimental evidence of device functionality, safety and efficacy before their approval and these evidences can be achieved with *in vitro* (lab-based) or *in vivo* (with animal/human trials) studies. Moreover, bench-testing ensures the device meets specific standards under various physiological conditions. Furthermore, experimental measurements guide design improvements by identifying potential weaknesses in the material or geometry and by assessing how the device behaves in complex and dynamic environments like the cardiovascular system, identifying area flow-induced issues, like thrombogenesis and hemolysis.

When treating hemodynamic, the investigation of hydraulic quantities (i.e., flow rate, pressure, pressure drop, EAO) alone is not enough; velocity vector fields and derived quantities must be considered, as they play a critical role in the success of device implants and in the progression of cardiovascular diseases, such as atherosclerosis. To this purpose, anemometric techniques, like laser Doppler velocimetry (LDV), Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV), offer detailed visualizations and quantifications of flow patterns (e.g., vortices and recirculation zones). In the past three decades, PIV and PTV have become standard measuring techniques in experimental fluid mechanics, providing qualitative and quantitative measurements of the flow fields. However, despite their power, both techniques come with certain limitations, primarily due to the complexity of the experimental setup, that involves critical components such as high-power lasers, scientific cameras, and synchronizers, which can increase the cost of experiments and require compliance with safety and regulatory standards. These financial and safety challenges have led some studies to explore low-cost and safer alternatives, using smartphone cameras, low-power lasers, or LEDs to investigate flow dynamics in aerospace or civil engineering. Stimulated from this scenario, the first objective of this thesis is to employ an alternative testbench based on the camera embedded inside a commercial smartphone and a low-power continuous-wave laser for PIV

measurements (named “smart-PIV”) in the cardiovascular fields, particularly for velocity measurements in realistic healthy and stenotic coronary artery phantoms. To assess the reliability of the measurements, the obtained Eulerian velocity vector fields were compared with the ones measured with a conventional PIV setup and the analysis was completed by evaluating the measurements errors affecting the velocity fields. Encouraged from the results obtained, the smartphone-based setup was then employed to perform a Lagrangian analysis of the flow field (named “smart-PTV”). The results were compared to the ones of the smart-PIV and conventional PIV by performing a Eulerian mapping of the Lagrangian data. Finally, the smart-PIV approach was employed to investigate the flow fields in presence of a coronary artery stent in fluid dynamic similarity.

The second objective of this work concerns the development of a testbench to assess the capability of a novel Cerebral Protection Device (FLOWer Embolic Protection device by AorticLab) to capture embolic debris. Such device should be employed during TAVI procedure to prevent cerebrovascular events (e.g. stroke), due to embolization if debris dislodged during several steps of the implant procedure. The device was tested under operational conditions using an aortic phantom and a commercial cardiovascular simulator to reproduce physiological conditions.

The last part of the thesis deals with the assembling of a testbench to *in vitro* investigate heart valve substitutes. A commercial pulse duplicator is employed to reproduce physiological flow and pressure waveforms. The pulse duplicator is firstly used for the characterization a St. Jude mechanical bileaflets aortic heart valve, considered the gold standard of heart valve prosthesis. Such device is investigated both hydrodynamically and through PIV measurements. Then, the testbench is conveniently modified for the testing of the Epygon mitral valve prosthesis (Affluent Medical).